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THE PROBABLE MECHANISM OF THE NIGHT SKY LUMINESCENCE IN THE CONTINUOUS SPECTRUM

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In 1951 it was shown [1] that the upper strata of the terrestrial atmosphere are a source not only of monochromatic radiation but also of radiation having a continuous spectrum. Recently one of us confirmed this [2] by means of a more perfect method, using several different light filters. The energy distribution in this spectrum was determined from observations, and in the interval 4720-5580 Å it was found to have a slight dependence on the wavelength. It was shown that the integrated radiation emitted in this interval varies, on different nights, from $1.2 \cdot 10^{-8}$ to $3.8 \cdot 10^{-8}$ erg/cm² sec deg²; that is, it may on occasion exceed by several times the radiation at λ 5577.

In the present paper, we are pointing out a possible mechanism for the production of this radiation. The ordinary electron-ion continuous emission (free-free transitions of electrons in the field of ions and recombinations of electrons with the ground level and excited levels of ions) is insufficient here, since the concentration of electrons and ions in the upper strata of the atmosphere does not exceed 10^6, which, with the comparatively small extent of the atmosphere, cannot give any continuous spectrum to speak of.

The abundance of neutral atoms and molecules in the atmosphere compels us to consider the process whereby negative ions may be formed. In this process, quanta must be emitted of frequency higher than frequency ν_0, corresponding to the ionization energy of the ion.

Unit volume of a gas containing n_e electrons and n_{r+1} ions (or, as in the present case, neutral atoms) radiates, per unit solid angle and per second, an energy [3]:-

$$j_\nu \rho \, d\nu = n_e n_{r+1} \frac{g_r}{u_{r+1}} \frac{h^4 \nu^3}{c^2} \frac{k'_\nu}{(2\pi m k' T_e)^{3/2}} \exp\left[- \frac{h\nu - h\nu_0}{\varkappa T_e} \right] d\nu, \quad (1)$$

where g_r and u_{r+1} are statistical weights, T_e is the electron temperature, and k'_ν is the coefficient of absorption calculated per negative ion. Among all the negative ions, it is only for hydrogen sodium, mercury, chlorine and oxygen that the quantities n_0 and k'_ν are known {4,5}. Since oxygen is one of the most abundant elements in the atmosphere, we shall calculate its emission.

The height of the layer radiating the continuous spectrum, as recently determined by a rather rough method {1}, is approximately 460 km. However, the height determination being very inexact, this figure means only that the radiation does not proceed from very low strata. Since the emission is most likely referable to one of the ionospheric layers, it is permissible to assume that it is generated in the F layer, which at night has a height of about 250 km, an electron concentration $n_e \approx 2 \cdot 10^5$ cm^{-3} and a neutral oxygen atom concentration $n_0 \approx 7 \cdot 10^{10}$ cm^{-3} {6}, provided we take the chemical composition of the atmosphere at that height to be the same as in the troposphere, with the oxygen dissociated and the nitrogen very feebly dissociated. It is not of great importance to know the degree of nitrogen dissociation. The temperature in these layers is approximately 1500-2000° {6}. The negative ion concentration is less than the electron concentration.

The dissociation energy of the negative oxygen ion, as determined by laboratory measurements, corresponds approximately to λ 5620 according to some findings, but to λ 4000 according to other findings. Bates {5} considers the first of these figures the more probable. The coefficient of absorption k'_ν at some distance from the limit, as Bates shows by a quantum-mechanical calculation, is equal approximately to $2\text{-}3 \cdot 10^{-18}$ cm^2, but near to the limit its trend is not known, since it depends on the unknown parameter of polarizability. It is most likely that k'_ν increases from the limit.

Let us calculate the emission from 1 cm^3 for wavelength 5220 Å, where the polarizability parameter does not so strongly affect the quantity k'_ν, which we may put as equal to $3 \cdot 10^{-18}$ cm^2. Using the values indicated above for the remaining parameters, we find by means of (1) that $j_\lambda \rho = 0.8 \cdot 10^{-14}$ erg/cm^3·sec·steradian·Å. If we consider the effective thickness of the emitting layer to be 70 km, the result we get is that the energy radiated per cm^2 per second within an angle of 1 square degree per Å is equal to $1.8 \cdot 10^{-11}$ erg, which is in good agreement with the data of observation. Thus the terrestrial atmospheric emission in the continuous spectrum may be entirely or partially due to the mechanism in question. It is at the present time impossible to carry out a comparison of the theoretical and observed energy-distributions in the spectrum, since we do not know the trend of k'_ν at the limit of the spectrum and the exact position of this limit is unknown. For the identification, we need to make observations in the longer-wave part of the spectrum, before the limit. If the identification is correct, we should not find any radiation there.

Now let us estimate how important certain other continuous spectrum emission mechanisms might be.

In the overwhelming majority of cases a continuous spectrum emission involves a partial conversion into radiation of the energy of the particles involved. As is well known, heavy particles, by the laws of conservation of energy and momentum, cannot convert the greater part of their energy into radiation. Therefore, to radiate a spectrum with the energy varying over a range higher than 0.4 eV, as in our present case, the requirement is that the energy of relative motion of the interacting particles should considerably exceed 1 eV. At $T_e \approx 1500\text{–}2000^\circ$ the number of such particles is comparatively small. Therefore, without excluding the above possibility, we should rather look for the source of the emission in the interaction of heavy particles with electrons. As we have already pointed out, the concentration of positive ions is too low to give any noticeable emission. The concentration of gases other than oxygen and nitrogen is always small; furthermore, the most abundant of them ... the inert gases ... have a very low electron affinity, so that the probability of their capturing an electron is small, and the radiated energy would have to be in the far infrared region of the spectrum. The bond energy of atomic and molecular nitrogen is also very small, which is in fact the explanation of the chemical inertness of nitrogen. According to a calculation of Massey, based on a extrapolation, the bond energy of an electron with a nitrogen atom is about 0.04 eV.

To estimate the part played by O_2 and N_2 molecules, we have to take into account that in the E layer (height about 100 km) the gas density is about two orders of magnitude higher than in the F layer, while the electron concentration at night seems to be lower by 1 to 1½ orders of magnitude. If the emission were due to molecules, then it would be stronger in the E layer, where the dissociation must be less; the height measurements, however, point to the F layer rather than the E layer. We may also conclude from this that in the E layer the oxygen cannot be strongly dissociated, and it must be that the oxygen concentration in this layer does not exceed the concentration in the F layer by more than 1 to 1½ orders of magnitude. When we have more accurate data on the electron concentration in the E layer, we shall be able to state this conclusion more precisely. We may say that there is a whole series of processes which will NOT serve as source of the observed radiation. But we must not prematurely conclude that the mechanism which we have examined is the only mechanism; there may indeed exist others, still unknown to us. Their existence does not deny the emission resulting from the formation of negative oxygen ions, which must constitute part of the night sky continuous spectrum.

With the aid of equation (1) it is easy to calculate that about 50 negative oxygen ions are formed per cm^3 per second. If these ions were to maintain themselves throughout the night, then in 1 or 2 hour's time the electron concentration would strongly decrease and the radiation would be extinguished.

Since n_e does not fall off rapidly during the night it is necessary to suppose that there exists a reverse mechanism which destroys the negative ions. Collisions with electrons are insufficient for this, as may easily be shown by calculation. The mechanism might be some photochemical reaction, or collisions with excited atoms. In particular, if it turns out that the energy of dissociation of the negative oxygen ion is smaller by 0.1-0.2 eV than what is at present accepted, then collisions with excited O-atoms in the $^1D_2$ state, the initial state for emission of the red lines λ 6300 and λ 6364, will be highly effective. The effective cross section for this process at energies near the dissociation value is very large ... of the order of 10^{-13} to 10^{-14} cm^2. If we take it that the λ 6300 and λ 6364 emissions originate in this same F layer, then the concentration of excited oxygen atoms, as determined by the brightness of these lines, is $n_2 \approx 10^4$.

The number of collisions of these atoms with negative ions, leading to destruction of the latter, is approximately equal to

$$n_2 n_1 v\sigma \approx 10^4 \cdot 10^5 \cdot 2 \cdot 10^5 \cdot 10^{-13} \approx 20 \text{ cm}^{-3} \text{ sec}^{-1},$$

assuming that the concentration of negative ions is $n_1 \approx 10^5$ (somewhat less than the electron concentration), and the relative velocity of the atoms $v \approx 2$ km/sec. We see that the rate of destruction of the negative ions in this case is close to the rate of their formation. There may occur other processes leading to the destruction of the negative ions, but they are of a character not important for the mechanism which we are here considering.

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REFERENCES

[1] D. Barbier, J. Dufay, D. Williams, Ann. d'Astrophys., 14, No.4, 399 (1951).

[2] K. K. CHUVAYEV, Dok. Akad. Nauk, 87, No.4 (1952).

[3] V. A. AMBARCUMIAN, E. P. MUSTEL', A. B. SEVERNY and V. V. SOBOL'EV. Kurs teor. astrofiziki /Course in Theoretical Astrophysics/, 1952.

[4] V. L. GRANOVSKI, Elektricheskii tok v gaze /The electric current in a gas/, 1, 1942, pages 181, 186.

[5] D. R. Bates, M. N., 106, 128 (1946).

[6] I. S. GERSON. Usp. Fiz. Nauk /Progress of the Physical Sciences/, 48, No.4, 561 (1952).